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FORCE-ENDURANCE CAPABILITIES OF EXTRAVEHICULAR ACTIVITY (EVA) GLOVES AT DIFFERENT PRESSURE LEVELS

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INTRODUCTION

The human hand is a very versatile tool which is considerably used in the EVA environment. Facilitation of extravehicular activities (EVAS), with simultaneous protection from the hazards of the EVA environment, are the often conflicting objectives of glove design. The conflict associated with providing hand protection while permitting adequate hand functioning has been widely recognized.

Numerous articles have been published concerning the effect of gloves on task performance (see, for example, Lyman and Groth, 1958, and Bradley, 1969). Most of these studies have addressed performance decrements with commercial gloves. Studies on EVA gloves have been totally absent but for the investigations performed by O'Hara et al (1988) and Bishu et al (1993a, 1993b). O'Hara et al (1988) studied two levels of hand conditions (gloved and bare-handed), two levels of pressure differential (0 psid and 4.3 psid), and three levels of hand size (small, medium, and large). Eleven subjects participated in an experiment in which six categories of performance measures were recorded: 1) range of motion, 2) strength, 3) tactile perception, 4) dexterity, 5) fatigue, and 6) comfort. The salient findings were

1) On the range of motion the glove and pressure effects were diverse and motion dependent. Effects for flexion were different from that for extension.
2) Glove reduced grip strength and pressure reduced it further. However, neither the glove nor the pressure had any effect on pinch strength.
3) The degradation in tactile perception was more noticeable with glove use than with pressure change.
4) Dexterity was reduced by both glove use and pressure change. Unpressurized glove use reduced dexterity by 50%, while pressurizing reduced it further by 30%.
5) The fatigue effects were the most uninterpretable due to complex electromyogram (EMG) signatures at different test conditions.
6) Perceived comfort reduced by 100% with unpressurized gloved conditions. Pressurizing reduced it further by 600%.

Bishu et al (1993a, 1993b) studied the effects of EVA gloves at different pressures on human hand capabilities. A factorial experiment was performed in which three types of EVA gloves were tested at five pressure differentials. The independent variables tested in this experiment were gender, glove type, pressure differential, and glove make. Six subjects participated in an experiment in which a number of performance measures—grip strength, pinch strength, the time to tie a rope, and the time to assemble a nut and bolt—were recorded. Tactile sensitivity was also measured through a two-point discrimination test. The salient results were

1) With EVA gloves, strength is reduced by nearly 50%.
2) Performance decrements increase with increasing pressure differential.
3) With EVA gloves there is a considerable reduction in dexterity.
4) Dexterity performance decrements increase with increasing pressure differential.

EVA activities involve certain levels of hand exertions for periods of time. Therefore, two issues are relevant here: the extent of exertion and the time of exertion. The studies discussed above have addressed the extent of exertion. The question of how gloves and pressure differential affect performance was addressed by O'Hara et al (1988), and Bishu et al (1993a, 1993b), and is described above. However, an important question which has not yet been addressed is how long a person can sustain a level of exertion while performing EVA activities. This deals with muscular fatigue and related issues. O'Hara et al (1988) attempted to measure fatigue through shifts in the median frequency of the EMG power spectrum; the results were uninterpretable for a number of reasons. A number of researchers have used the functional relationship between force exerted by a muscle group and the time of endurance as a predictor of muscle fatigue (Rohmert, 1960; Monod and Scherrer, 1965). In general, endurance time increases with decreasing force. Bishu et al (1989) used endurance time for evaluating container handles. The objective of this investigation was to answer the question "How long can a person sustain a level of exertion while performing EVA activity?" In other words, the objective was to develop force-time relationships for a variety of EVA glove-pressure combinations.

It was expected that such relationships will, besides providing some insight on the endurance of people performing EVA activities, also throw some light on the phenomenon of static muscle fatigue.

Objective

To develop force-time relationships for a number of EVA glove-pressure combinations.

METHODS

Subjects

Six voluntary subjects (three males and three females) participated in this experiment.

Independent Variables

The independent variables tested in this experiment were gender, glove type, pressure differential, and level of exertion. Three levels of pressure differentials were used in this experiment (0 psid, 4.3 psid, and 8.3 psid). The intent was to develop a force-endurance relationship at each pressure, for each glove. Three different gloves were tested here: the current 3000 series Weightless Environment Training Facility training shuttle gloves (referred to hereafter as glove C) and two advanced developmental gloves (referred to hereafter as gloves A and B). Four levels of exertion—100%, 75%, 50%, and 25%—of maximum voluntary contraction (MVC) were used here. The performance measure was the endurance time, or the length of time a person could sustain the level of exertion. To summarize, the independent variables with their respective levels were

1) Gender	male and female
2) Pressure	0, 4.3, and 8.3 psid
3) Glove condition	A, B, C, and Bare hand
4) Level of exertion	100%, 75%, 50%, and 25%

Glove Box

The testing was performed in the Advanced Suit Laboratory in Building 34 at the Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA), Houston, Texas. The actual tests were conducted inside a glove box. The glove box is cylindrical in shape, approximately 2 ft in diameter and 4 ft in length with an internal volume of 13 ft^3 (figure 1). On each side of the glove box are two end caps made of Plexiglas and bolted through eight bolts. About midway along the axis of the glove box are two 6-in. circular openings in the cylinder wall, placed shoulder-width apart, which provide access and attachment points for the EVA glove and arm assemblies. The glove box was connected to a vacuum pump and could be evacuated to any desired pressure level. A gauge on the outer cylinder wall was calibrated to read the pressure differential. The set-up for this experiment was similar to the one described in Bishu and Klute (1993).

Procedure

There were 36 different treatment conditions in this experiment. The order of presentation of the 36 conditions was randomized for each subject. Table 1 shows experimental design for this study.

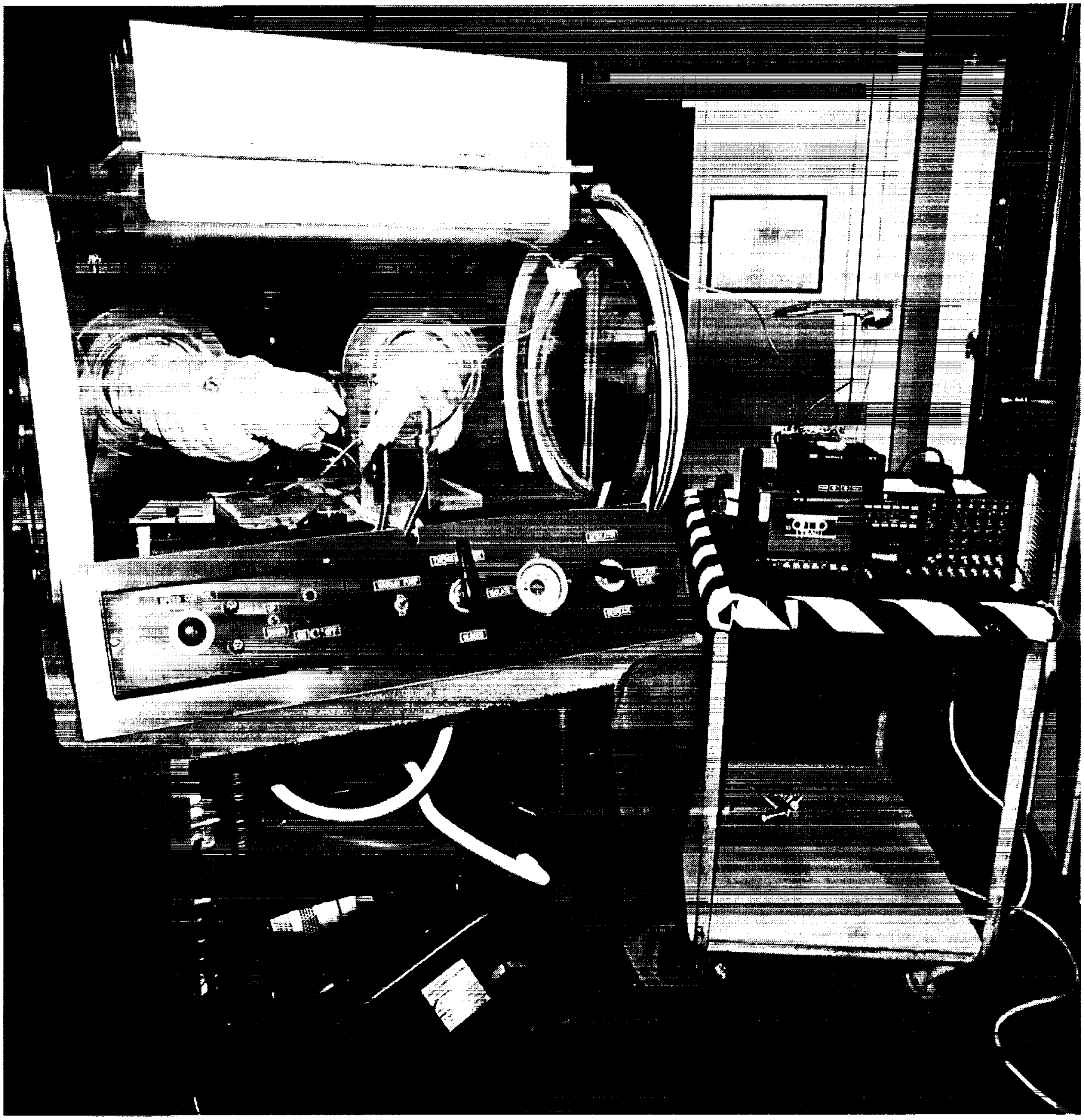

Figure 1. Glove box.

Table 1. Experimental Design

PRS	A 100%	A 75%	A 50%	A 25%	B 100%	B 75%	B 50%	B 25%	C 100%	C 75%	C 50%	C 25%
O PSI												
4.3 PSI												
8.3 PSI									*	*	*	*

* Bare-handed condition at 100%, 75%, 50%, and 25% MVC.

Initially, the MVC for each glove-pressure combination was measured using a Jamar hand dynamometer. The dynamometer was wired to a TEAC recorder. The four levels of exertion at any glove-pressure combination was computed with respect to the MVC at that combination. A trial consisted of the following steps. A 24-hour rest period followed each trial. As a result, the experiment lasted 36 days in all.

1) The exertion level for the "condition of the day" was first calculated.
2) The glove box was pressurized to the "condition of the day."
3) The subject donned the relevant EVA for the "condition of the day" and exerted to the computed level of gripping force on the Jamar hand dynamometer.
4) The subject maintained the level of exertion for as long as possible before quitting voluntarily.
5) The endurance time was recorded through the TEAC recorder and a stop watch.

RESULTS

A multifactor analysis of variance (ANOVA) was performed on the data for two dependent measures—endurance time and exertion force. The ANOVA summary is presented in table 2.

Table 2. Summary of Analyses of Variance

Effects	Endurance time	Exertion force
Exertion level	***	***
Gloves	ns	***
Pressure	ns	***
Subjects	***	***
Gender	ns	***
Exertion*Glove	ns	***
Exertion*Pressure	ns	***
Glove*Pressure	ns	na
Glove*Gender	ns	***
Pressure*Gender	ns	***

*** = p<.0001, ns = not significant, and na = not applicable.

It is very interesting to note that, while all the main effects and the first order interactions are significant for exertion force, the endurance time seems to depend only on the exertion level.

Exertion Force Results

Figure 2 shows the plot of the exertion level*glove interaction for the exertion force. It is apparent that the force exerted at various exertion levels tested here is significantly higher for bare hand than for gloved hand. This is obvious and expected given the fact that gloves tend to reduce grip strength. Figure 3 shows the exertion level*pressure interaction for the exertion force. The difference between 0 psi and the other two pressures is significant, with the greater forces being exerted at 0 psid than at 4.3 and 8.3 psid.

Figure 4 shows the plot of the glove*pressure interaction on the exertion force. Bare-handed force is much greater than the gloved-hand force. Among the two developmental gloves tested here, subjects seem to exert greater force with glove B than with glove A. Figure 5 shows the plot of the gender* glove interaction on the exertion force. Female subjects demonstrated lower strength capabilities than male subjects and this difference is consistent across all glove configurations tested. Figure 6 shows the plot of the gender*pressure interaction for the exertion force. Again, female subjects demonstrated lower strength capabilities than male subjects and this difference is consistent across all the pressure differentials.

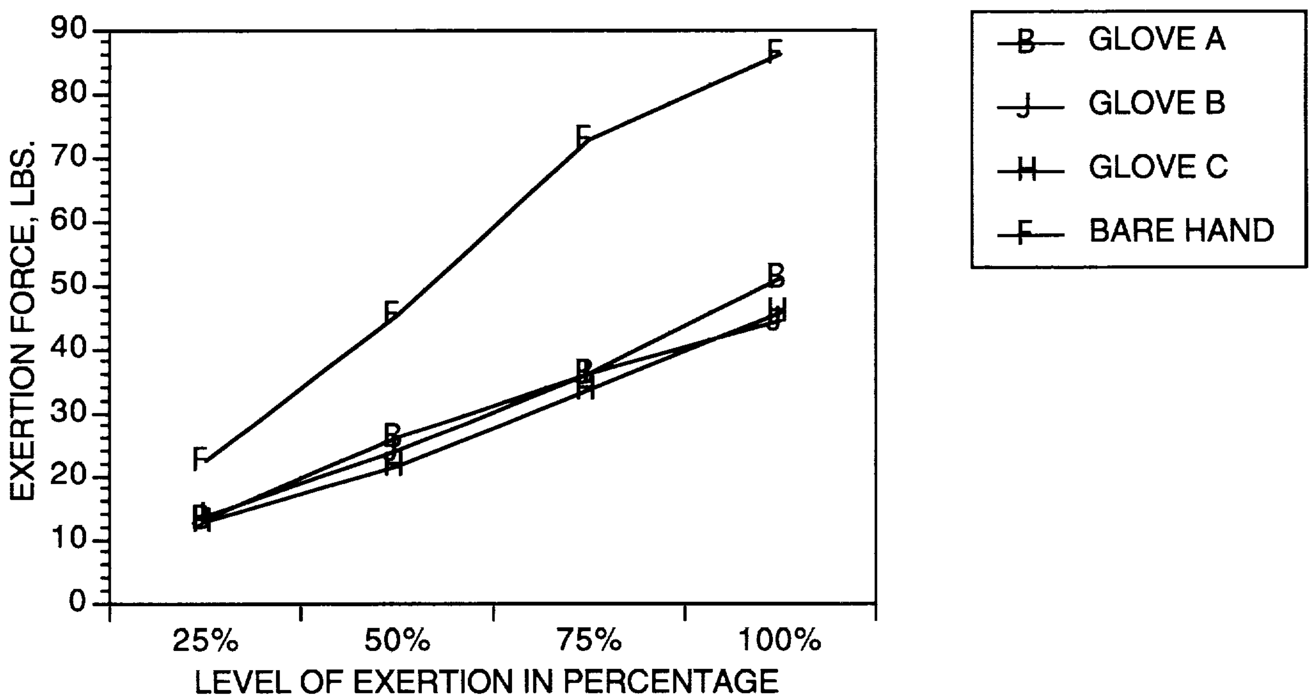

Figure 2. Glove*exertion level interaction on exertion force.

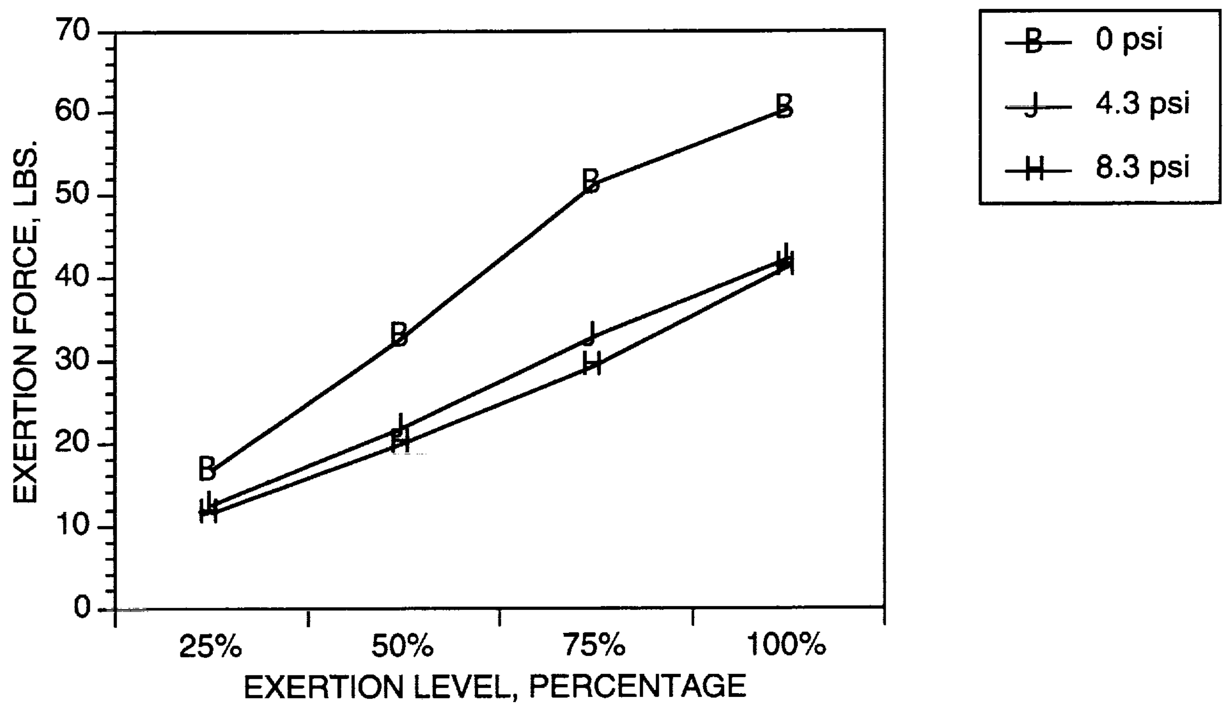

Figure 3. Exertion level*pressure interaction on exertion force.

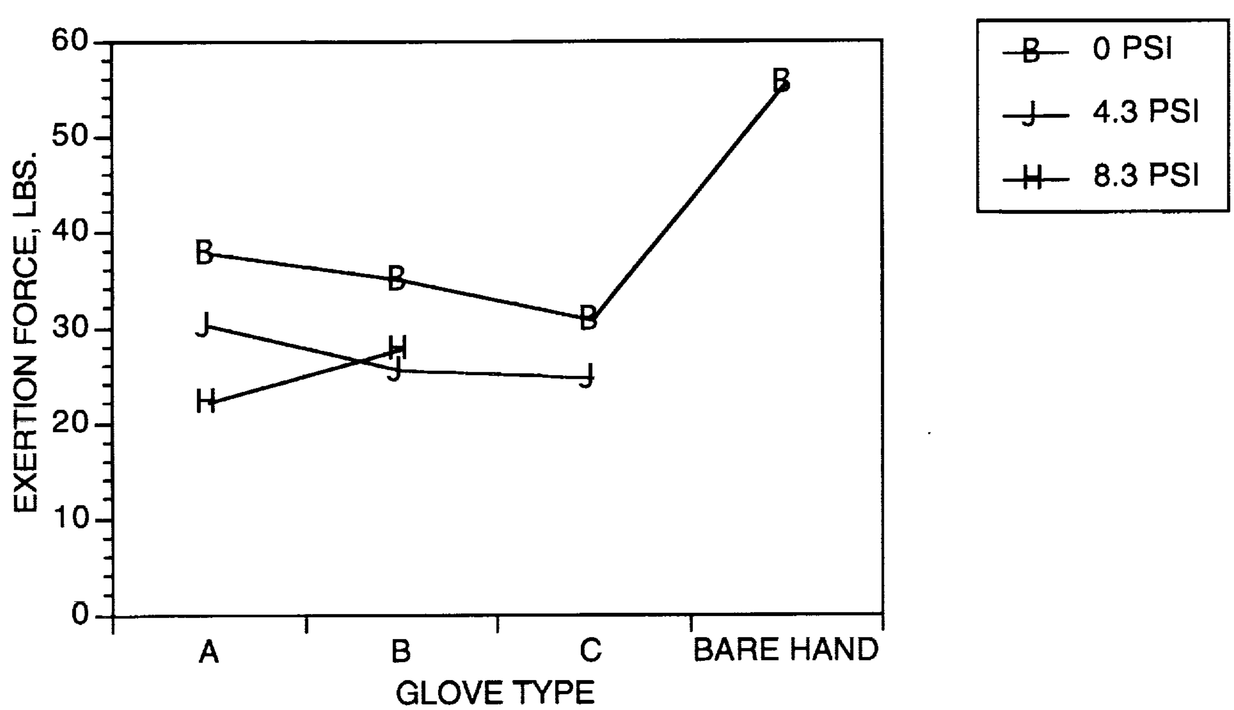

Figure 4. Glove*pressure interaction on exertion force.

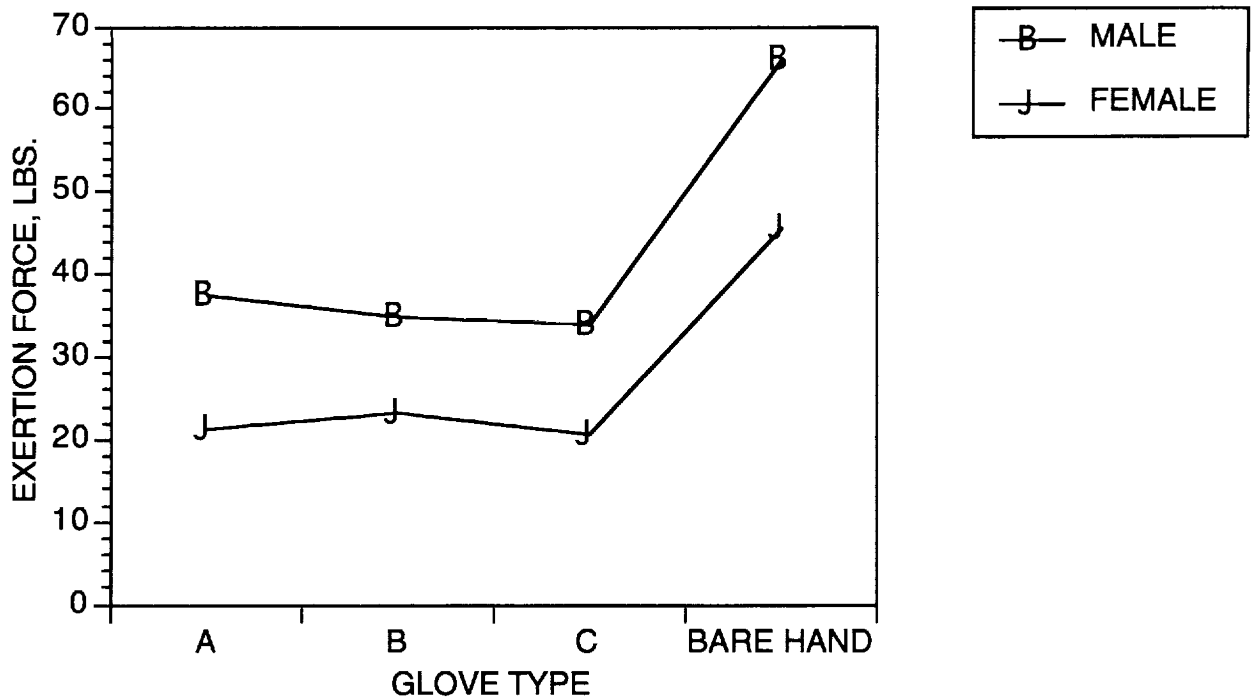

Figure 5. Gender*glove interaction on exertion force.

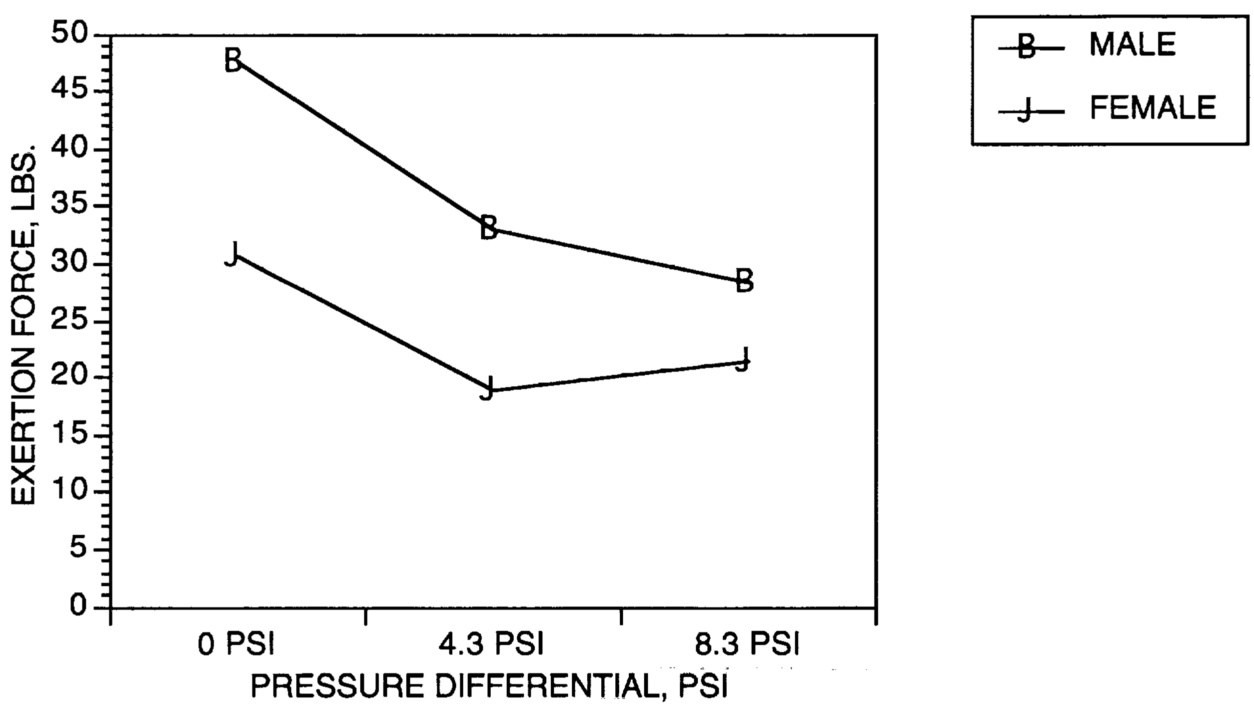

Figure 6. Pressure*gender interaction on exertion force.

Endurance Time Results

Perhaps the most interesting finding of this experiment is the lack of significance of almost all factors for the endurance time. As is seen in table 2, the subject and the exertion level are the only significant effects. In this author's opinion, this result has profound significance for the theoreticians as well as for the practitioners. For the practitioner, prescriptions for endurance time for any activity can easily be provided by just determining the exertion level of that activity. For the theoreticians, the need to answer the question "Why should the endurance time not be dependent on pressure differentials or on the type of glove donned?" should be overwhelming. Figure 7 shows the plot of the exertion level effect on the endurance time, across all glove configurations and pressure differentials. The endurance time is shortest at the 100% exertion level, and longest at the 25% exertion level. As the plot in figure 7 resembled a negative exponential relationship, a similar model was fit on the data. The model was determined to be

$$\text{Endurance time} = 435.257\ e^{-3.0792p} \qquad R^2 = .6232.$$

where p = level of exertion expressed as a ratio of absolute exertion in a configuration to the maximum exertion at that configuration. According to this equation the maximum possible endurance (at p = 0) is 435.257 seconds, while minimum endurance (at p = 100%) is about 7 seconds.

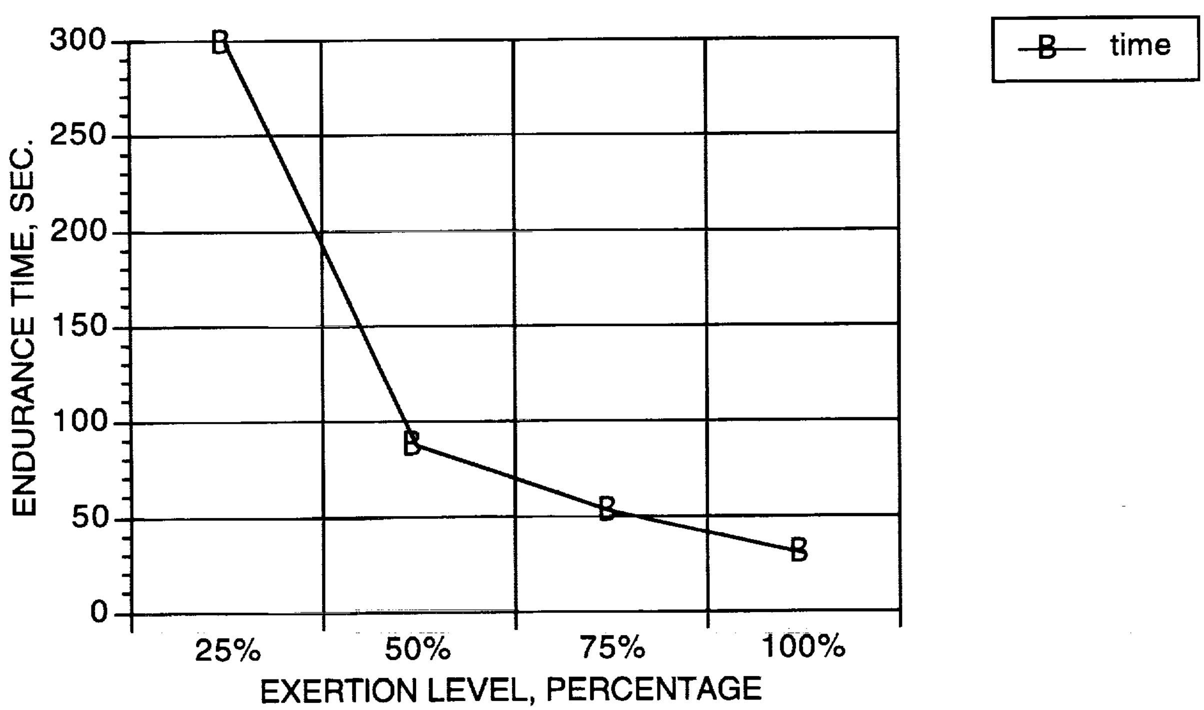

Figure 7. Endurance time vs. exertion level.

DISCUSSION AND CONCLUSION

Among the two dependent variables tested in this experiment, the findings on exertion force are consistent with those reported by these authors in their earlier study (Bishu and Klute, 1993). Female subjects tended to perform slower, and showed lower strength capabilities. The fit of the glove to the hand, which was not controlled in this experiment, may have caused the gender difference. The next finding of this experiment is that both pressure change and glove use reduce performance. These findings are consistent with those reported by O'Hara et al (1988) and others (Wang et al 1987; Cochran et al 1986). With gloves, there is an apparent increase in grip span and an earlier pressing of fingers with each other. The former should increase the grip strength, while the latter should reduce the strength. It appears that the effects of increase in grip span with gloves is somewhat counteracted by the reduction in the inter-digital movements and range of motion when gloves are donned, resulting in net reduction in performance.

Perhaps the most interesting finding of this experiment is the lack of significance of almost all factors for the endurance time. A glove effect, pressure effect, glove*exertion level, and pressure*exertion level interaction was expected. Results indicate that none of these effects were significant. Two explanations exist: these may have been an artifact of sample size and due to some lack of control in the experiment; or, more likely, the physiological cost may be the same for bare hand and gloved/pressurized conditions at any level of exertion. For example, let us say that a person exerts 100 lb of grip strength at his/her 100% bare-handed condition, and 80 lb of grip strength at his/her 100% gloved condition. Judging from the results of this study, the muscular exertions of the lower and upper arm musculature may be the same for both cases. In such a case, the fatigue can be expected to be the same for both. The same argument can be made for other levels of exertions. At the 50% exertion level, the grip strength for the bare-handed and gloved condition will be 50 lb and 40 lb, respectively; the upper arm and lower arm musculature may again be fatiguing at the same rate as indicated by similar endurance time. This is consistent with the findings reported by Sudhakar et al (1988). In comparing gloved and bare-handed performance, the authors reported similar EMG activity of the lower arm muscles in both conditions, though the gloved hand resulted in reduced strength capability.

Thus, endurance time can be represented by the following set of equations:

$$\text{Endurance time} = ae^{bp},$$

where a = maximum endurance time
b = fatigue rate, and
p = level of exertion

And exertion force at any exertion level p can be:

$$\text{Exertion force} = k(GS)p$$

where GS = Maximum grip strength in a bare handed condition
k = hand condition factor ($k = 1$ for bare-handed, and < 1 for gloved conditions), and
p = exertion level

With these equations, one can describe glove/pressure conditions through k (the hand condition factor).

In summary, it is seen that performance decrements occur with gloves and with increasing pressure differential. However, the endurance time is dependent only on the exertion level expressed as a percentage of maximum exertion force in that hand condition. It is possible to develop a general exponential equation for endurance time, and describe the hand condition through a "hand condition" factor. Size was not controlled in this study and may have had an impact on the findings. More research is needed to determine the exact effects of size and glove material on performance. Such data will be invaluable to the designer of hand gloves.

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13. ABSTRACT *(Maximum 200 words)*
The human hand is a very useful multipurpose tool in all environments. However, performance capabilities are compromised considerably when gloves are donned. This is especially true to extravehicular activity (EVA) gloves. The primary intent of this study was to answer the question of how long a person can perform tasks requiring certain levels of exertion. The objective of this study was to develop grip force-endurance relations. Six subjects participated in a factorial experiment involving three hand conditions, three pressure differentials, and four levels of force exertion. The results indicate that, while the force that could be exerted depended on the glove, pressure differential, and the level of exertion, the endurance time at any exertion level depended just on the level of exertion expressed as a percentage of maximum exertion possible at that condition. The impact of these findings for practitioners as well as theoreticians is discussed.

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